Effect of Energy Storage Devices in Hydrothermal Power Systems by using Various Controllers

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Abstract—**The Automatic Generation Control is an integral part of Energy Management System. In this particular work an interconnected hydrothermal power system was studied in detail with the corresponding response of Energy storage devices mainly the SMES and CES that played a vital role along with state the variation in operation i.e.; frequency response and tie-line effect with the conventional controllers determined below: Proportional (P),Integral(I),Proportional Integral(PI) and Proportional Integral Derivative (PID). These marked up an optimal operation point of the Hydro thermal response in Load variations.**

Keywords: **Automatic Generation Control, Super conducting magnetic energy storage device, Capacitive Energy Storage, Integral Squared Error,PID controller.**

I. Introduction

Automatic Generation Control is a very important subject in modern power system operation for supplying sufficient and reliable electric power. Each control area strives to meet its own demand in addition to the scheduled interchanges with other areas so that the entire power system can supply consumer demands at nominal frequency and voltage levels and be in an equilibrium state. But in practice, the loads are random and continuously changing with time. Further, due to physical/technical limitations, the ability of generation to track the varying loads is limited. Thus, Automatic Generation Control (AGC) of an interconnected power system is concerned with controlling the real power output of electric generators within a control area in response to changes in system frequency and tie-line loading in an economical way so that the scheduled system frequency and established interchange with other areas are maintained. To achieve the integrated operation of a power system, an electric energy system must be maintained at a desired operating level which is delineated by nominal frequency, voltage profile and load flow configuration. An energy storage device with a quick response time can be added to power system to reduce the oscillations of system frequency and tie line power due to random load pattern. Several Energy storage devices have been designed and proposed in the last few decades such as flywheels, battery storage, compressed air, pumped hydro, fuel cells, Capacitive Energy Storage and Superconducting Magnetic Energy storage, etc. However, they have their own practical limitations as pointed out in [5-7]. Capacitive Energy Storage (CES) and Superconducting Magnetic Energy storage (SMES) are the latest in energy storage devices. This paper investigates the dynamic performance of various conventional controllers ie; P, I, PI and PID controllers uses CES and SMES units in an interconnected hydrothermal power system to improve the system performance. The advantages of CES are that they are relatively cheap, high energy efficiency which is close to 100%, maintenance free, relatively higher energy density and environment friendly as opposed to other systems. The capacity of a CES unit can be upgraded by simply adding capacitors in parallel. To damp out the oscillations in the shortest possible time, automatic generation control including SMES unit is used. In the proposed system the effect of in AGC on SMES control is investigated for the improvement of LFC.Where at the end this study we will conclude the best part of the AGC with a proper and quick damped frequency oscillation. When a small load disturbance in any area of the interconnected system occurs, tie-line power deviations and power system frequency oscillations continue for a long duration, even in the case with optimized gain of integral controllers. The optimum values of the controller parameters are obtained by Integral Squared Error (ISE) performance indices. Finally, the different dynamic responses are plotted with 1% step load perturbation in thermal area.

II. Hydro-Thermal Power System Model

The AGC system under analysis is composed of an interconnection of thermal system and a hydro system. The model of a two-area power system suitable for a digital simulation of AGC is developed for the analysis as shown in Fig. 1. Two areas are connected by a weak tie-line [Equation B]. When there is sudden rise in power demand in one area, the stored energy is almost immediately released by the SMES and CES through its power conversion system. This action also happens when there is a sudden decrease in load demand.

III. Capacitive Energy Storage Unit

A capacitor stores the energy in its electrostatic field created between its plates in response to applied potential across it. A Capacitive Energy Storage (CES) unit consists of, from a circuit point of view, a super capacitor or a cryogenic hyper capacitor, a power conversion system and the associated protective circuitry. The dimensions of the capacitor are determined by the energy storage capacity required. Initially the capacitor is charged to its set value of voltage from the utility grid during its normal operation. Once

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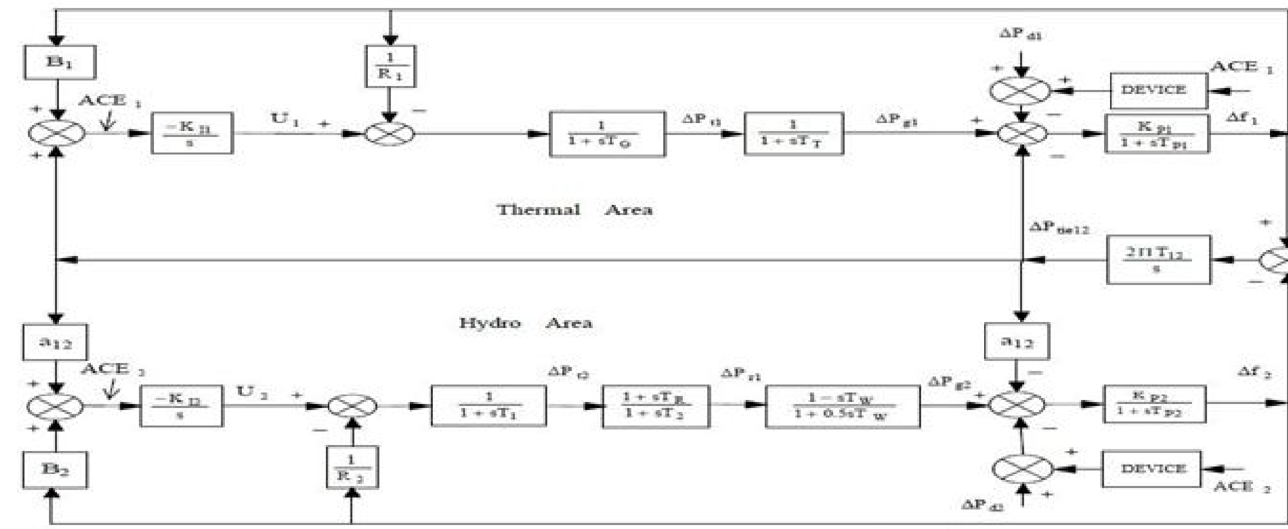

Figure 1. LTI model of interconnected hydrothermal system with Energy storage devices

the voltage reaches its rated value, it is kept floating at this value and the CES is now ready to be put into service. When there is a sudden rise in load demand, the stored energy is almost immediately released to the grid. The capacitor immediately gets charged to its full voltage value, thus absorbing some portion of the excess energy in the system. As the system returns to its steady state, the excess energy absorbed is released and the capacitor voltage attains its normal value. The set value of the CES voltage has to be restored at the earliest after a load perturbation so that the CES unit is ready to act for the next load perturbation. As per reference [2-4].

ACE=BΔf+ΔPtie;i, j=1,2(Equation B "ACE Response")

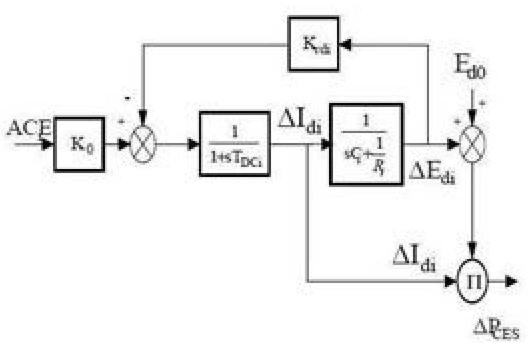

Figure 2. CES Unit: Block diagram representation with formulation

(Equations A " CES response")

$$\Delta P_{CES} = \Delta I_{d0} \times \left(E_{d0} + \Delta E_{di}\right) \; ; i=1, 2$$

$$\text{Where } \Delta E_{di} = \frac{\Delta I_{di}}{C_i s + \frac{1}{R_i}} \; ; i=1, 2.$$

IV. SMES System

The superconducting coil is contained in a helium vessel. Heat generated is removed by means of a low-temperature refrigerator. The energy exchange between the superconducting coil and the electric power system is controlled by a line commutated converter Fig. 3 the schematic diagram of SMES unit. Once the superconducting coil gets charged, it conducts current with virtually no losses, as the coil is maintained at extremely low temperatures. When there is a sudden rise in the load demand, the stored energy is almost released through the converter to the power system as alternating current. As the governor and other control mechanisms start working to set the power system to the new equilibrium condition, the coil current changes back to its initial value. Similarly, during sudden release of loads, the coil immediately gets charged towards its full value, thus absorbing some portion of the excess energy in the system and as the system returns to its steady state, the excess energy absorbed is released and the coil current attains its normal value The control of the converter firing angle provides the dc voltage Ed appearing across the inductor to be continuously varying within a certain range of value, it is maintained constant by reducing the voltage across the inductor to zero since the coil is superconducting. These detail as per reference [1].

The inductor current deviation is used as a negative feedback signal in the SMES control loop[as in equations C]. So, the current variable of SMES unit is intended to be settling to its steady state value. If the load demand changes suddenly, the feedback provides the prompt restoration of current. The inductor current must be restored to its nominal value quickly after a system disturbance, so that it can respond to the next load disturbance immediately. Fig. 4 shows the block diagram of SMES unit. The equations of inductor voltage deviation and current deviation of SMES unit of area i (i=1,2,…N) in Laplace domain are as follow. Where ΔEdi is the incremental change in converter voltage (kV), ΔIdi is the incremental change in SMES current (kA),

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KIdi is the gain for feedback ΔIdi (kV/kA), Tdci is converter time delay(s), K0i is gain constant (kV/unit ACE) and Li is inductance of the coil (H).

$\Delta E(s) = K\ 1\ [B\ \Delta f\ (s) + \Delta P\ (s)] - [K1 * \Delta I\ (s)]$

$I(s) = \Delta E(s) *$ (Equation C "SMES Response")

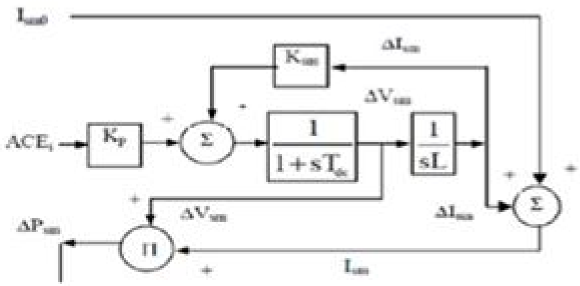

Fig 3.SMES block diagram

V. Dynamic Responses And Discussions

To demonstrate the beneficial damping effect of the proposed controller, computer simulations has been carried out for different load changes using the MATLAB environment. The system performances with various conventional controllers for AGC with and without CES & SMES units are studied as in Fig. 4-6.

Dynamic responses for frequency perturbations ($\Delta f1$and $\Delta f2$) and tie-line perturbations ($\Delta Ptie$,12) following a 1% step load disturbance in thermal area with and without Energy storage devices.

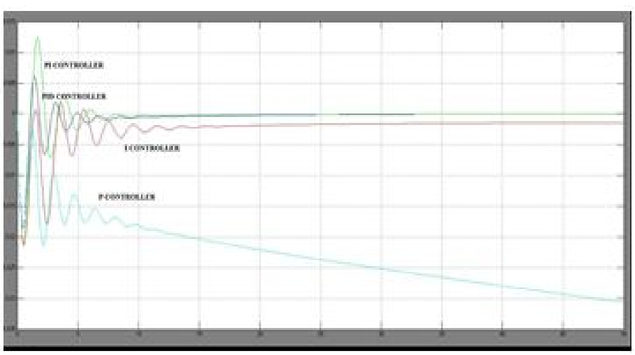

Fig 4: $\Delta f1$ Thermal plant effect without device

This shows the dynamic responses for the frequency deviations ($\Delta f1$ and $\Delta f2$) and tie-line power fluctuations ($\Delta Ptie12$) for a 1% step load perturbation in the thermal area without and with Energy storage units. The variation is found in both the Hydro as well as Thermal plant. It is evident that, the transient behaviour of the area frequencies and tie-power have been improved significantly in terms of peak deviations in the presence of the Energy storage units. As the paper follows to explain each and every criteria to determine the variation felt .The first two tables determines the particular variation of the four factors as considered to state an oscillation of any system. Similarly the detailed study of the Hydro Thermal system is required so the CES device impact can be handled through where the part of the improvement is well tabulated that states which has a reduction in the rise time and a quick reach out of the depleted system stability as shown. As per the tabulate (Table 1&3 as per simulation results)on we can conclude that the CES is an optimal quick responding technology which is cheap as the expenses are set to be one of the implementing criteria. Then the particular most advanced Device that is the SMES device with a proper mathematical modelling and clear variation in the frequency as well as the best optimal output is compared in the tabulation (Table1&5 as per stimulation) finalizing that this gives a best output with minimum oscillation making the very much quick response. Similar response of hydro are tabled at 2,4,6

Table I: Thermal Plant without device

THERMAL PLANT PROFILE	RISE TIME	SETTLING TIME	OVER SHOOT	peak
only P controller	0.329	4.2	0.5266	1.16
only I controller	0.868	6.19	16.2	1.16
only PI controller	0.794	5.82	16.2	1.16
Only PID controller	0.665	4.49	0.755	1.01

Table II: Hydro Plant without device

HYDRO PLANT PROFILE	RISE TIME	SETTLING TIME	OVER SHOOT	peak
only P controller	1.19	35.8	94.3	0.779
only I controller	4.48	63.6	21.5	1.21
only PI controller	4.37	63.9	23.4	1.23
Only PID controller	3.48	49.3	0	1

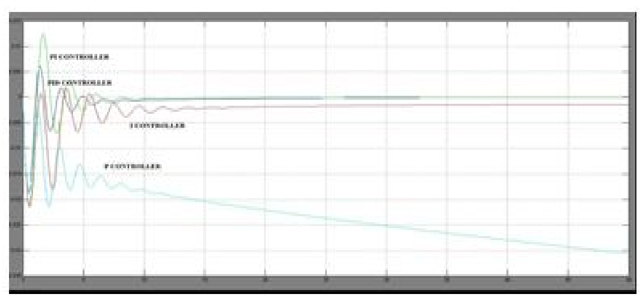

Fig 5: $\Delta f1$ Thermal plant effect with CES device

Table III: Thermal Plant with CES device

THERMAL PLANT PROFILE	RISE TIME	SETTLING TIME	OVER SHOOT	peak
P controller + ces	0.0634	4.69	86.5	1.8
I controller + ces	0.779	12.7	28.4	1.29
PI controller + ces	0.911	15.7	10.5	1.11
PID controller + ces	0.291	3.38	4.93	1.05

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Table IV: Hydro Plant with CES device

HYDRO PLANT PROFILE	RISE TIME	SETTLING TIME	OVER SHOOT	peak
P controller + ces	0.2	85.5	124	1.51
I controller + ces	175	340	0	0.998
PI controller + ces	0.996	676	8.16	1.08
PID controller + ces	0.101	0.734	9.5	1.09

Fig6: Δf1Thermal plant effect with SMES device

Table V: Thermal Plant with SMES device

THERMAL PLANT PROFILE	RISE TIME	SETTLING TIME	OVER SHOOT	peak
P controller + smes	0.00541	0.203	76.3	1.76
I controller + smes	0.641	4.63	9.89	1.1
PI controller + smes	0.119	1.39	11.4	1.11
PID controller + smes	0.0501	1.03	10.2	1.1

Let us consider the figures 4,5,6 as the best example as per the thermal plant taking with the PID controlled output as the part of comparision the CES device charging time is 1.5- 3 secs which gives the frequency deviation to be settled within 16 secs which was greater than 25 secs at non deviced PID in special condition , But the charging effect of the SMES device states that they are even faster than the previous devices that are charged within 1 sec with high instant charging well the other device charges gradually.This makes the the particular device to reach out the stabilization within 5 secs.

Table VI: Hydro P lant with SMES device

HYDRO PLANT PROFILE	RISE TIME	SETTLING TIME	OVER SHOOT	peak
P controller + smes	0.165	89.6	58.6	1.01
I controller + smes	4.72	1.97	4.48	1
PI controller + smes	1.25	89.9	6.9	1.07
PID controller + smes	0.961	87.4	4.94	1.05

VI. Conclusion

The simulation studies have been carried out on a two area power system to investigate the impact of the proposed intelligently controlled AGC including CES & SMES units on the power system dynamic performance. The results show that the proposed PID scheme with the Energy storage device is very powerful in reducing the frequency deviations under a variety of load perturbations.

Appendix

Pr = 1200MW, R=2.4Hz/p.uMW, B=0.424, Tp=20s, Kp=120Hz/p.u.MW, vd=0.1KV, C=1F, Edo = 2KV

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